

THE WORLD OF CHEMISTRY

Program #20

ON THE SURFACE

Producer Robert Kaper

Air Script: October 31, 1988

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Annenberg/CPB Project Logo and Music

Funder Credits

MONTAGE: Surface tension,
microscopic shots, washing
machine, adhesive tape,
catalysts

NARRATOR (MUSIC under):
Surfaces. Surprisingly, their chemistry
is profound, not superficial at all. The
surface of any substance is different
from what's inside. That's why liquids
have surface tension, detergents clean
clothes, adhesives bond, and catalysts
speed up reactions. All these behaviors
have one thing in common, action on the
surface.

SUPER: ON THE
SURFACE

THE WORLD OF CHEMISTRY OPEN: Montage, Music, Logo

RH in lab with
chemical models

ROALD HOFFMANN (SYNC):

Surfaces are special. Surfaces, or interfaces, are boundaries, first of all, between a solid and a liquid, a solid and a gas, or even between two liquids that don't mix with each other. The atoms at a surface are different from those in the interior or bulk of a solid. The reason that they're different is very simple, they've got fewer neighbors. There's nothing above them. Because the atoms at a surface are lacking some neighbors, their bonding capacity is still available. In fact, they will bind with any other molecule that comes near. They are reactive. And when a liquid or gas approaches a solid -- and that's typical situation in chemistry, that liquid can't feel the atoms in the bulk of the solid. All it sees is the surface.

MONTAGE: Computer
chips, oil, race car, soap,
adhesives, catalytic
reaction

NARRATOR (MUSIC and NAT
SOUND under):

Reactions take place on surfaces in all kinds of ways. Computer chip manufacturers depend on surface chemistry to bond the micro-thin layers that make up logic circuits. Oil and grease bind to metal surfaces and keep them from binding with each other.
(cont.)

NARRATOR cont:

Detergents bond with the surface of dirt to pull it into the wash water. Adhesives form bonds with the surfaces of solids and hold them firmly together. And molecules bonding with catalyst surfaces may react much faster than usual, and sometimes in entirely different ways. What is there about a surface that makes it so special? Series demonstrator, Don Showalter.

DS in lab

DON SHOWALTER (SYNC):

Here's a surface. It's the surface of water. It's different from the water inside, in the bulk. Why the difference? We all know that metal is much more dense than water. That's why it sinks. But what would happen if I carefully placed a piece of metal onto the surface? It's supported. It holds it up. There's a tension in the surface that supports the metal. Now, I could even put a bigger piece of metal on there. It supports that piece of metal, too. Here's another example of surface tension. Let me get some of this water, put a few drops onto this wax paper. Now, look how strong the surface tension is. I can drag these drops all across this paper without breaking them apart. Put them all together then. The water does not wet the wax paper. (cont.)

DON SHOWALTER cont:

The forces of attraction between the individual water molecules are stronger than the forces of attraction between the water and the wax paper. Is there any way to reduce water surface tension to make it wet things better? Well, we can add a chemical that acts on surfaces, a surfactant, plain old detergent. It breaks down the surface tension, so it is no longer strong enough to support the metal, and it's no longer strong enough to hold the drop together. It collapses, and wets the wax paper.

GRAPHIC: Surface tension
of water at the molecular
level

NARRATOR (MUSIC under):

Water molecules inside the liquid pull together in all directions. Surface molecules are pulled only to the side and downward. The sideward and downward forces create a tension on the surface molecules. The water surface acts like an elastic skin. Surfactant molecules, added to water, line up at the air-water interface. Surfactants are long hydrocarbon chains with a polar or ionic end. The polar or ionic ends form bonds with water. The hydrocarbon portions stick up through the surface. They interrupt the hydrogen bonding between the water molecules and break down the elastic skin.

Shots of Shell Oil's Chemical
Division

NARRATOR (NAT SOUND under):
Future lab technicians take heed. Here's
your competition, a tireless robot arm
testing surfactants around the clock for
the Chemical Division of Shell Oil. The
surfactants being tested are designed for
laundry detergents. The chemical is
added to a miniature washing machine,
along with a little water, and cloth
samples soiled with carefully measured
amounts of dirt. A sample of the dirty
wash water is taken for laboratory
analysis to see how much dirt has been
removed. Surfactants here are designed
for everything from washing clothes to
extracting petroleum from underground
reservoirs. Dr. Herb Benson.

INTERVIEW: Dr. Herbert
Benson, Chemical Division
of Shell Oil

SUPER: Herbert Benson

DR. HERB BENSON (SYNC):
One of the uses of surfactants, developed
some years back, was to enhance the
recovery of oil from underground
reservoirs. During normal recovery of
oil, only about one-third, or 33 percent,
of the oil is obtained.

Oil well shots

NARRATOR (NAT SOUND under):

But a water surfactant mixture pumped down a well reduces the surface tension between oil and water. The oil flows more freely so more can be pumped out, sometimes twice as much as without a surfactant.

INTERVIEW: Dr. Herbert Benson cont.

DR. HERB BENSON (SYNC):

It seemed to us that removing crude oil from porous rock was very similar to removing soil from fabrics.

Shell Oil lab shots,
analyzing surfactants

NARRATOR:

So Dr. Benson's laboratory has taken an oil well surfactant and is modifying it to produce a new cold-water detergent. The surfactant collects around oily dirt in a thin layer that's thousands of times more concentrated than in the wash water. So it should be able to clean clothes much better than a conventional surfactant that's evenly distributed in the water.

GRAPHIC: Surfactant
properties at the molecular
level

NARRATOR (MUSIC under):
Oily dirt on a fabric can't be removed
with just water. Water doesn't form
bonds with nonpolar substances like oil,
but the nonpolar ends of surfactant
molecules form bonds with oil, and the
polar ends with water. So they can pull
oil away from cloth fibers and into the
water.

MONTAGE: Adhesives and
their uses

NARRATOR (MUSIC and NAT
SOUND under):
The bonding action of adhesives depends
on many of the same mechanisms that
work with surfactants. Adhesives turn
up in all kinds of places. Even in the
human body. Surgeons sometimes hold
incisions together with adhesive tape
instead of sutures. And dentists bond
caps to teeth with fast-setting glues.
Adhesives also hold automobile parts
together, glue wood veneers together to
make plywood, and hold tape in place.
Like surfactants, adhesive molecules
have to form bonds with other molecules
at interfaces, and they also have to be
able to wet other surfaces. Dr. Al
Pocius of the 3M Company.

INTERVIEW: Dr. Al Pocius,
3M Company

SUPER: Al Pocius

DR. AL POCIUS (SYNC):

What we have, when we are trying to make a roll of adhesive tape, is we want it to be in a situation where we can store it for many years and not have the tape roll just unfold on itself, or telescope, as we call it. And then we want it just to stay in that sort of integral form until the time when we want to use that adhesive tape, and then we want to be able to just unroll it and be able to then apply it and stick it. Now, that requires a lot more technology than one -- than one would normally think, because now we want to have a material that has a tape on one side that is very, very sticky and adherent, but yet it can't stick to the other side. But, at the same time, it has to stick well enough so that the adhesive just doesn't fall apart on its own.

Jet airplanes and
airplane parts

NARRATOR (NAT SOUND under):

Dr. Pocius also investigates adhesives that hold together airplane parts.

Adhesives often back up the rivets that hold aluminum skin panels in place, and sometimes completely replace them.

INTERVIEW: Dr. Al
Pocius cont.

DR. AL POCIUS (SYNC):

What we have here is a section of a helicopter rotor blade that has an extensive amount of adhesive bonding on it. The first thing that we see here is the fact that this structure that's inside of the rotor blade is a honeycomb structure. The honeycomb structure, in itself, is made by adhesively bonding strips of aluminum together and then stretching them apart to generate a honeycomb type of situation. And then the adhesives are used in order to join the honeycomb structure itself to the skins that are present on the helicopter rotor blade. The same type of structure is used in the control surfaces on aircraft -- that's the flaps and things that you see operational on an aircraft.

Fibers, building a jet
airplane, airplane
flying

NARRATOR (NAT SOUND under):

Some aircraft are made from synthetic fibers and adhesives forming a composite material similar to that in graphite tennis racquets. Pound for pound, the composite is stronger than aluminum, so it's beginning to replace aluminum in many advanced aircraft. Adhesives can withstand the severe stresses on jet planes because of the strong bonds they form with surface molecules.

Applying adhesives

DR. AL POCIUS (VO/SYNC):

Adhesives bond things together for the same reasons that materials remain as liquids or as solids. Typically, the forces that are there between molecules are there because of the electron cloud that surrounds any atom or molecule.

INTERVIEW: Dr. Al
Pocius cont.

And as they're moving around the nucleus, any one point in time those electrons are on one side or the other side of the nucleus. And, at those points, they create an instantaneous charge separation, which then can cause an interaction between that atom or molecule and another atom or molecule.

Adhesive bonding

NARRATOR:

This instantaneous charge separation means simply that the positive portion of one molecule can attract the negative portion of another. This attraction is the main reason why adhesive molecules bond to a surface.

Catalysts, factory shots

NARRATOR (MUSIC under):

Catalysts. The effect of catalysts on chemical reactions also depends on molecules bonding with surfaces. But unlike the bonding of adhesives, molecules bond only briefly with catalyst surfaces. There they form new compounds much faster than they would on their own. Catalysts make modern chemistry possible. Chemical companies make nearly all their products with the aid of catalysts, and catalysts in your car's exhaust system convert pollutants to relatively harmless carbon dioxide and water. There are countless ways a molecule can react with a catalyst.

GRAPHIC: Generalized catalytic action on the surface, at the molecular level

NARRATOR (MUSIC under):

But it generally starts by bonding temporarily with catalyst atoms as it moves from one location to the next. The bonds formed with the catalyst may weaken the molecular bond and cause it to break. Other molecules striking the surface go through similar reactions. The atoms or fragments from the molecules continue moving around the catalyst surface. If two of them collide, they may join to form a new molecule. The catalyst has caused the reaction without being changed itself.

Chemist at work, computer
analysis, model of molecule

NARRATOR (NAT SOUND under):
Until recently, there was no way to tell exactly how catalysts affected chemical reactions. All chemists could do was brew up new catalyst formulations and try them out to see what happened. But thanks to new technologies, researchers can now observe the behavior of molecules on catalyst surfaces. And with the knowledge gained from these observations, they can design catalysts to do specific jobs. Scientists at the National Bureau of Standards, outside Washington, D.C., have built a model of ammonia molecules on an iron catalyst. Catalyst surfaces are rarely smooth. They're usually broken up into different levels, or steps. Dr. Ted Madey.

INTERVIEW: Dr. Ted
Madey, National Bureau
of Standards

SUPER: Ted Madey

DR. TED MADEY (SYNC):
Each of the colors here represents iron atoms at a different atomic level. This is one atom step higher than that level, and this level is one atom step higher than this. (cont.)

DR. TED MADEY cont:

As the ammonia molecule adsorbs on the surface, it's spinning, but it also has a probability of hopping about on the surface, and it can do so and find its way to a step edge, one of these step sites here between the top layer and the layer immediately beneath. Now, at a step, the electronic charge in the iron tends to slosh over and fill in the troughs in the layer beneath. The ammonia molecule has positive charge on the outward end, on the hydrogen end of the molecule. This positive charge on the ammonia interacts with this negative charge in the troughs, and the ammonia molecule actually tips over. Now, as it tips over, the hydrogen atoms on the ammonia start to bond with the iron atom at the step site, and ultimately the ammonia can dissociate into fragments. For example as shown over here. We have an NH species, where two hydrogen atoms have split off from the ammonia molecule. Back over here at another step, we've depicted an ammonia molecule which has broken up into NH₂ species plus individual hydrogen atoms. The technique that we use to get information about the structure of molecules on surfaces involves the bombardment of the surface with low energy electrons and breaking of bonds. (cont.)

DR. TED MADEY cont:

For example, in the case of ammonia, as absorbed here, electronic bombardment breaks an NH bond and causes a hydrogen ion -- in this case as a proton - - to fly off in the direction of the ruptured bond. If this bond is broken, the ion would fly in this direction. If that bond is broken, the ion would fly in that direction. Now, in order to capture these ions, we place a detector above the surface to intercept the ion beams.

MONTAGE: Computer analysis of molecules, researchers in oil company lab, factory shots, textiles, tires, car bumper

NARRATOR (NAT SOUND under):

The hydrogen ion beams from a spinning molecule are thrown out in a circular pattern. They appear on the detector as a smoky ring. A computer converts the ring to a three-dimensional image that shows the distribution of the hydrogen ions and their energy levels. But a molecule that's bonded to the surface has stopped spinning, so it makes a different pattern. If it's got two hydrogens left, they show up on the detector as two large peaks at fixed locations. This type of pure research is one way scientists investigate catalyst's activity. But there's much more applied research to develop catalysts for a specific purpose. (cont.)

NARRATOR cont:

Oil companies, for example, invest considerable sums in equipment such as electron microscopes, to develop new catalysts to make fuels and chemicals from petroleum. Research and development here is a multi-million dollar gamble. There's no guarantee the money spent will produce anything useful. But, if it does, the payoff can be enormous. Just one catalyst breakthrough made more than half a billion dollars for Standard Oil of Ohio, now part of BP America. SOHIO researchers came up with a new catalytic process, in the late 1950s, that soon dominated all others in the production of acrylonitrile. That's the acrylic plastic that's made into textiles, tires, and car bumpers. Oddly enough, SOHIO researchers weren't even trying to produce acrylonitrile at first. They simply wanted to make a metal oxide catalyst, convert waste propane gas from petroleum refining into something more valuable. Dr. Jeanette Grasselli.

INTERVIEW: Dr. Jeanette
Grasselli, BP America

SUPER: Jeanette Grasselli

DR. JEANETTE GRASSELLI (SYNC):
The theory, the hypothesis at the time,
was that we could take the oxygen from
the catalyst, insert it into the propane,
relatively unreactive molecule. So this
was a tough technical objective. And, in
turn, regenerate or take the catalyst back
to its original oxidized form by using
oxygen from the air.

Catalyst research,
factory shots

NARRATOR (NAT SOUND under):
But the theory didn't hold up. Propane
was too stable to react, and the catalyst
particles broke down in service.
Management gave them three more
months to show results, so they made
some changes. They replaced propane
with a more reactive refinery gas,
propylene. They made their catalyst out
of different metal oxides, and they added
ammonia to promote or speed up the
reaction.

INTERVIEW: Dr. Jeanette
Grasselli cont.

DR. JEANETTE GRASSELLI (SYNC):
To our surprise, ammonia reacted,
rather than just encouraging the reaction
to go faster as a promoter, the ammonia
reacted and became part of the reaction
sequence, and we made acrylonitrile in
one step.

Catalysts, plastic beads

NARRATOR (MUSIC and NAT
SOUND under):

The researchers had struck pay dirt.
Their new catalyst, combined with
ammonia, had made a valuable plastic
out of a nearly worthless gas.

INTERVIEW: Dr. Jeanette
Grasselli cont.

DR. JEANETTE GRASSELLI (SYNC):
At this point, I clearly remember the
rockets went off in the hallway. Our
research director had a way of, for
every significant research achievement,
setting off some rockets in the hallway,
at which point everyone in the
laboratory was alerted that a Eureka
had, in fact, occurred.

Factory shots

NARRATOR (NAT SOUND under):
Management quickly saw the value of
the new process and wasted no time
building a plant to use it.

INTERVIEW: Dr. Jeanette
Grasselli cont.

DR. JEANETTE GRASSELLI (SYNC):
In 1960, when our plant came on
stream, acrylonitrile was selling for 28
cents a pound. We were making it for
14 cents a pound. And we shut down
every other commercial process.
Today, 90 percent of the world's
acrylonitrile is still manufactured by the
SOHIO process.

MONTAGE: Catalysts

NARRATOR (MUSIC and NAT
SOUND under):
Catalysts are manufactured in many
different shapes: powders, granular
particles, even spaghetti-like extruded
strands. They have to be rugged enough
so they won't crumble in use. They
must also have as much surface area as
possible. The more surface area on each
catalyst particle, the more molecules can
react on it.

DS in lab

DON SHOWALTER (SYNC):
What difference does surface area make?
Here we have a material in two different
forms. It's a starch product. Here it is
in pellet form. Here we've ground it
into a fine powder. There's the same
mass of material in both. However, the
powder has millions of times more
surface area than the pellets. (cont.)

DON SHOWALTER cont:

Now, what would happen if we added water to these? Water bonds with this material at the surface. Let's put the pellets into this beaker, and we'll add the water, just about a liter of water. Well, not much happens. There's not much surface area for the water to bond with. Now, what would happen if we did the same thing with the powder? I'll pour the powder into this beaker, and we'll pour the water in. And look at that! There's so much surface area in that powder that all the water is bonded to the finely divided material.

Catalyst research, computer models

NARRATOR (MUSIC and NAT SOUND under):

With most catalysts, the reacting surface is on the outside. But there's a special category of catalysts whose main reacting surface is in pores, or holes. They're called zeolites, or molecular sieves. By controlling the size of the pores, zeolite designers can tailor-make catalysts to react only with molecules of a specific size or shape. One of the pioneers in molecule sieve research is Union Carbide's Dr. Edith Flanigen.

INTERVIEW: Dr. Edith
Flanigen, Union Carbide

SUPER: Edith Flanigen

DR. EDITH FLANIGEN (SYNC):

The name "molecular sieve" is derived from the fact that you can actually sieve molecules. We have here an N-Butane molecule, a normal paraffin, that can go through the pore and be absorbed in the cavity. On the other hand, if we take isobutane, which is a branch-chained paraffin, it's too large to go through the pore, and it's excluded.

Research, factory shots,
chemists at work in labs,
New Zealand sheep and
mountains, Mobil's New
Zealand plant, gas station

NARRATOR (MUSIC under):

Through the work of Dr. Flanigen and her colleagues, the company has become the world's largest synthetic zeolite producer. Other companies, too, have made major breakthroughs in the zeolite business. Mobil Synthetic Zeolite converts methanol, wood alcohol, directly into gasoline. It's a way to produce gasoline without the need for petroleum, a process that might be an answer to a future energy crisis. It already has been a salvation for one little country, New Zealand. They have no petroleum. (cont.)

NARRATOR cont:

But they do have plenty of natural gas, which is easily converted to methanol. So when oil prices skyrocketed in the 1970s, New Zealand asked Mobil to build a plant to convert methanol to gasoline with its zeolite catalyst. New Zealand will be well protected when the next oil crisis comes around.

SUPER: ON THE SURFACE

MONTAGE: Models of molecules, lab demonstrations, program graphics, surfactants, adhesives

NARRATOR (MUSIC under):

To review, the atoms or molecules that make up a surface have unsatisfied bonding capacity. Molecules on a liquid surface are under tension and act like an elastic skin. Surfactant molecules interrupt the bonding between surface molecules and break down the tension. The surfactant molecules in soaps and detergents can bond with oil and with water. Adhesive bonding is caused mainly by attractions between positive and negative portions of molecules. Molecules form temporary bonds with the atoms in catalyst surfaces. These bonds may weaken and break molecular bonds, causing new molecules to form. Zeolite catalysts, or molecular sieves, can be designed to react only with molecules of a specific shape and size.

RH at chemical plant

ROALD HOFFMANN (SYNC):

The study and utility of surfaces illustrates one point that I want to leave with you, and this is the interplay of pure and applied chemistry. Are these two parts of our science, pure and applied chemistry, separate? In no way. They are intermingled with each other at every step. It's impossible to build a modern chemical plant without a fundamental understanding of heat and energy transfer -- of the properties of surfaces that are in that plant. And the problems that arise in that industry feed back and generate problems for university professors to study. What's marvelous is how it all fits together. A process that's developed in a laboratory can be taken, with a few years of hard labor, to a multi-million dollar business. A problem in production, the failure of a catalyst, economic pressure from the competition, can lead to entirely new fundamental chemistry.

Credits, Closing Montage, Closing Music

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